INFESTATION OF A BOTANICALS WAREHOUSE BY *PLODIA INTERPUNCTELLA* AND *EPHESTIA ELUTELLA* (LEPIDOPTERA: PYRALIDAE)[1, 2]

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ABSTRACT: Botanicals are crude vegetable medicinals, including roots, leaves, bark, or other plant materials used to produce pharmaceuticals, herbal supplements, and other products. Dried botanicals often become infested with insects and mites during storage, but little is known about these infestations. The objective of the present study was to characterize an infestation of stored botanicals by the Indianmeal moth, *Plodia interpunctella*, and the tobacco moth, *Ephestia elutella*, in a North Carolina warehouse. The moth populations were monitored for one year with an array of pheromone-baited sticky traps. Spatial analysis of numbers captured showed broadly overlapping, but distinct distributions, suggesting that both species prefer roots but that *P. interpunctella* has a broader host range. Seasonal variation in rates of capture reflected the effect of temperature cycles on population growth and flight activity, and suggested that *E. elutella* populations may suffer less winter mortality or may recover more quickly than *P. interpunctella*.

Botanicals are unrefined parts of medicinal plants, including roots, leaves, bark, and other plant materials that are harvested, dried and then stored until they can be processed and used in the manufacture of pharmaceuticals, nutritional supplements, and other herbal products. Familiar examples include ginseng, ginkgo, St. John's wort, saw palmetto, and witch hazel. The popularity and use of herbal supplements and other herbal products has grown substantially in recent years, and the economic value of botanicals used annually in their production is estimated conservatively at $300-500 million (Michael McGuffin, American Herbal Products Association, personal communication). During storage, the dried materials are subject to infestation by a variety of stored-product insects, but little is known about these infestations. The present paper reports an infestation of a botanicals warehouse at Boone, NC by the tobacco moth, *Ephestia elutella* (Hübner), and the Indianmeal moth, *Plodia interpunctella* (Hübner).

The Indianmeal moth is cosmopolitan, and the tobacco moth is nearly so but does not occur in the tropics (Cox and Bell, 1991). Both species are general feeders and have been reported to infest a very wide range of dry plant materials, including dried fruit, nuts, cereal grains and cereal products, oilseeds, cacao, and drug plants (Richards and Thomson 1932). El Halfawy (1977) reported *P. interpunctella* from stored medicinal and aromatic plants in

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Egypt, Kalinovic and Rozman (2000) reported *E. elutella* from stored medicinal plants and herbal tea in Croatia, and Weidner (1973) listed records of both species from a variety of medicinal and aromatic plants in Germany. Arbogast et al. (2001) reported infestations of the Indianmeal moth and the almond moth, *Cadra cautella* (Walker), in a Florida botanicals warehouse used alternately for storage of saw palmetto berries, *Serenoa repens* (Bartram) Small, and passion flower, *Passiflora incarnata* (L.).

The objective of the present study was to gain a better understanding of insect problems in stored botanicals by characterizing and comparing the infestations of *P. interpunctella* and *E. elutella* in terms of spatial distribution, association with specific botanicals and seasonal variation.

METHODS AND MATERIALS

The warehouse complex at Boone (Fig. 1) was a steel structure consisting of a warehouse, milling area, and loading dock attached to the back of a two-story brick office building. The warehouse and milling area were completely enclosed, and the loading dock was enclosed on two sides. The warehouse itself was 24.4 m. wide by 21.3 m. deep and contained five steel shelf units. Botanicals were stored in various containers on these shelves and on the floor. We monitored moths in the warehouse from June 1998 through July 1999 with pheromone-baited sticky traps (SP-Locator traps with SP Minimoth pheromone dispensers, Agrisense-BCS Ltd., Pontypridd, Mid Glamorgan, UK). The warehouse was mapped, a grid of 20 trap locations was laid out (Fig. 1), and the stored botanicals were listed by trap location, using the family, scientific, and common names for medicinal plants according to Torkelson (1996). Trap locations were specified in a rectangular coordinate system with the origin at the left front corner of the warehouse adjacent to the offices. The spacing of traps was always > 4 m, the measured active space of the SP-Locator Trap (Mankin et al., 1999). The traps were attached by means of Velcro at a height of about 1.2 m, either to the walls or to the shelf units. Monitoring was continuous during 1998, and traps were checked at intervals ranging from 7 to 32 days, but usually 7-14 days. The number of moths captured by each trap was recorded and the trap was replaced. Pheromone lures were replaced monthly. During 1999, the warehouse was monitored for one week out of each month. Traps were set up at monthly intervals and removed after one week. New traps and lures were used each month.

The spatial distribution of trap captures in each observation was analyzed by contour mapping (Arbogast et al., 1998; Brenner et al., 1998). For this purpose, the x, y-coordinates of the traps and the corresponding numbers of moths captured were entered in Surfer 7 (Golden Software, 1999), which posted observed values of trap catch to the appropriate coordinates on a floor plan of the warehouse (entered as a base map). The software creates a denser grid of trap catch values by interpolation, using one of several algorithms. We used radial basis functions (with the multiquadric function), which produces good representation of most small data sets (< 250 observations) (Golden Software, 1999). Spatial distribution was summarized for the entire study period by summing the numbers captured by each trap during the study and then analyzing the totals.

Trap captures were summarized by season, and for this purpose, Summer was defined as June, July and August; Fall as September, October and November; Winter as December, January and February; and Spring as March, April and May. Seasonal variation in moth population density, or in level of moth activity, was studied by examining rates of capture, rather than numbers captured, because trapping effort (number of traps x number of days the traps were deployed) varied from season to season. Rates of capture (total numbers captured divided by trapping effort) were determined for each trap during each season, and seasonal medians were compared. Median rates of capture were tested for significant differences among seasons using the Kruskal-Wallis one-way analysis of variance by ranks, and multiple pairwise comparisons of seasons were made with the Tukey test. Within each season, median rates of capture for each species were compared using the Mann-Whitney rank sum test. Nonparametric statistics were used, because the rates of capture were usually not normally distributed. All calculations were done in SigmaStat 2.03 (SPSS, 1997).

Temperature was not recorded inside the warehouse, which was not heated or air conditioned, but we estimated seasonal means, mean seasonal maxima, and mean seasonal minima outside the warehouse by averaging monthly values reported by the National Climatic Data Center (NOAA) for a nearby weather station (Boone SE 1). The pattern of seasonal variation within the warehouse should reflect the pattern outside, but with diurnal fluctuation dampened by the moderating effect of the enclosure.

RESULTS

A total of 1,924 *P. interpunctella* and 887 *E. elutella* were captured at the twenty trap locations during the study. The number of moths captured by any trap during a given period depended on the position of the trap in the warehouse, and the spatial distribution of numbers captured varied somewhat with season. However, when the number of moths captured at each trap position was summed over the duration of the study and the totals analyzed spatially, it became apparent that most captures occurred in two well-defined centers, one for each species, although the two centers overlapped broadly (Fig. 1). The focus of the *E. elutella* distribution was on the right side of the warehouse at trap location n (Fig. 1A) and that of the *P. interpunctella* distribution was on the left side at trap location f (Fig. 1B).

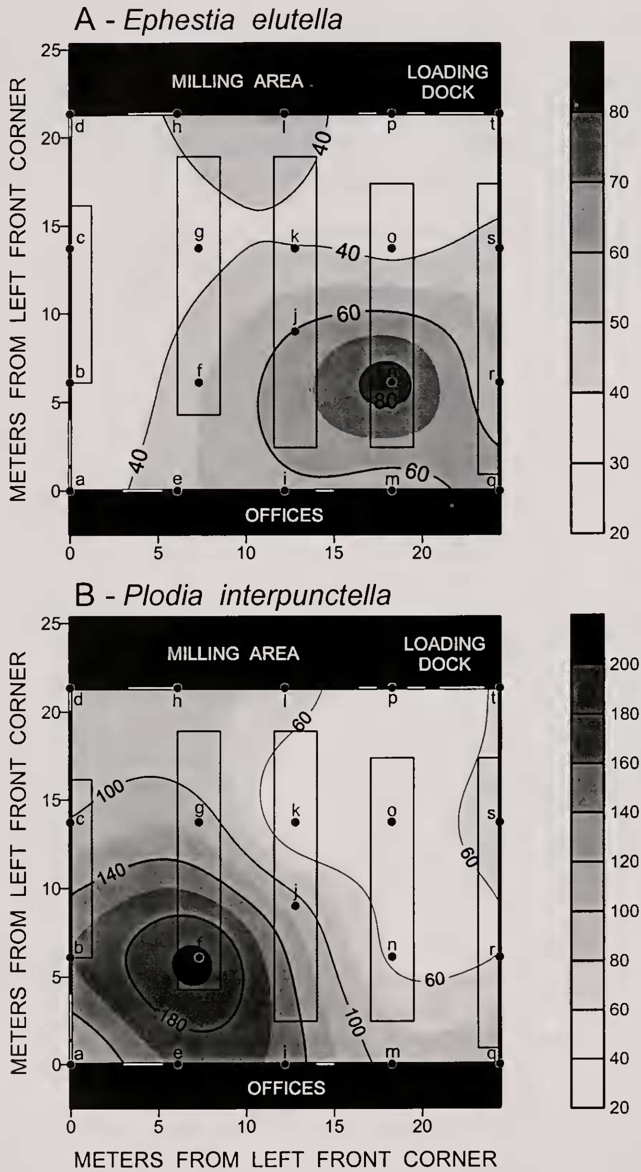

Figure 1. Spatial distribution of *E. elutella* (A) and *P. interpunctella* (B) in a botanicals warehouse at Boone, NC. Floor plan shows only part of the milling area and loading dock at the rear of the warehouse and offices at the front. Contours represent total numbers trapped between June 1998 and July 1999. Shelf units are indicated by open rectangles and trap locations by solid dots. Lower case letters identify individual trap locations.

Median rates of capture for the warehouse as a whole varied significantly with season (Kruskal-Wallis, P < 0.001). The capture rate for combined species was highest in the summer and fall of 1998 and lowest during winter 1998-99 and spring 1999 (Fig. 2). Combined capture rate was slightly higher during the summer of 1999, but the difference in median rates between spring and summer was not statistically significant. Combined capture rate was significantly lower during the summer of 1999 than during the previous summer, as was the capture rate of *P. interpunctella,* but the capture rate of *E. elutella* was about the same.

The difference in the median rates of capture between *P. interpunctella* and *E. elutella* was not statistically significant during the summer of 1998 (Mann-Whitney, P = 0.156), but during the fall, the median rate was very much higher for *P. interpunctella* (P < 0.001). Very few *P. interpunctella*, and no *E. elutella*, were captured during the winter, but during the spring and summer of 1999 the median capture rate was higher for *E. elutella* (P = 0.050, P < 0.001).

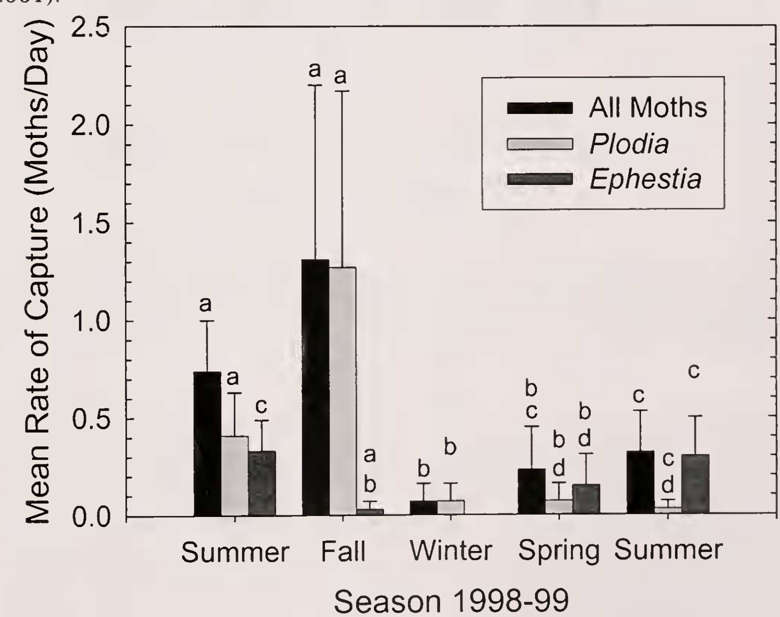

Figure 2. Seasonal variation in capture of *P. interpunctella* and *E. elutella* in a botanicals warehouse at Boone, NC. Lower case letters indicate multiple pairwise comparisons of seasons within species (or within combined species) (Tukey Test). For each species (or combined species), seasons with the same letter have median capture rates that are not significantly different (P < 0.05). See text for statistical comparison of species within season.

The botanicals stored in the warehouse are listed in Table 1, and descriptive statistics for outside air temperature at Boone are presented in Fig. 3.

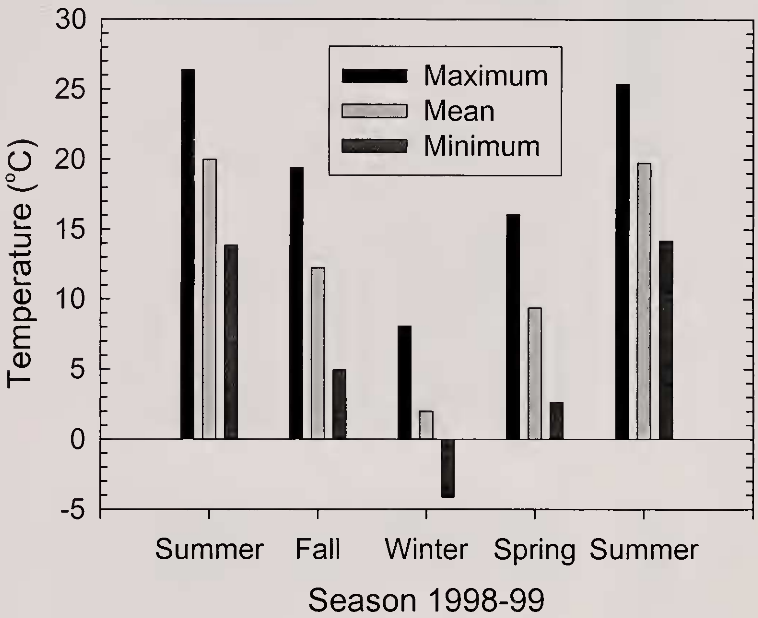

Figure 3. Seasonal mean, mean seasonal maximum, and mean seasonal minimum temperatures at Boone, NC. Seasonal temperatures were calculated from monthly mean, mean monthly maximum, and mean monthly minimum temperatures reported by the National Climatic Data Center (NOAA) for a weather station at Boone (Boone SE 1).

DISCUSSION

The warehouse was packed with a wide variety of plant materials in bags, paper drums, and other containers, which we did not examine for signs of infestation; therefore, we cannot say with certainty which botanicals were infested and to what degree. The Indianmeal moth and tobacco moth have very broad host ranges, as already noted, and could conceivably have infested any of the botanicals. Nevertheless, we can gain some idea about infestation by comparing the spatial distribution of trap catch (Fig. 1) with the distribution of botanicals relative to traps (Table 1). Over the course of a year, the greatest number (96) of *E. elutella* (Fig. 1A) were captured near witch hazel bark and beth root, and the lowest numbers (< 40) were captured near various kinds of bark (including some witch hazel) and herbs (or leaves). Of the 10 trap locations for which the number of captures was > 40, 8 were near roots. And all of the trap locations in which the number of captures was > 60 were near roots. The pattern was different in *P. interpunctella* (Fig. 1B). The greatest number (225) were captured near witch hazel bark and poke root, but most of the locations with > 60 or > 100 moths captured were not near roots. The difference in distribution between the two species could reflect differences in ability to utilize various hosts. That is, the host preference of both may be various kinds of roots, but *P. interpunctella* may be better able to utilize less satisfactory material such as bark and herbs. This hypothesis is also supported by the higher numbers of *P. interpunctella* captured throughout the warehouse. At any given trap location, the number of *P. interpunctella* captured was greater than the number of *E. elutella* captured (Fig. 1). The difference could also reflect local competitive displacement, such as that demonstrated in interacting populations of the maize weevil, *Sitophilus zeamais* Motschulsky, and the Angoumois grain moth, *Sitotroga cerealella* (Olivier), (Arbogast and Mullen, 1987; Arbogast et al., 1998). *P. interpunctella* can apparently out-compete *E. elutella* but cold winters hold it in check as discussed below. The dominance order of the two species is reversed after a cold winter.

Seasonal variation in median capture rates of both species (Fig. 2) can be attributed to the suppressive effect of low temperature on flight activity as well as on population growth rate. We are not aware of any information about the lower temperature threshold for flight in these moths, but the temperature range for development of *E. cautella* is 10-30°C, and that for development of *P. interpunctella* is 18-35°C (Cox and Bell, 1991). Diapause induced by low temperature or short photoperiod may greatly extend the developmental period of both species. The mean maximum temperature at Boone was about 8°C and the mean minimum about – 4°C during the winter of 1998-99 (Fig. 3). With these outside temperatures, temperatures inside the unheated steel warehouse were almost certainly below the lower thresholds for flight and development during much of the winter, and were probably low enough to produce significant winter mortality. In fact, the lower rates of capture in the spring and early summer (observations ended in mid July) of 1999 indicate population decline of both species during the winter followed by a lengthy recovery period. Capture rates indicate that population levels of the two species were about the same during the summer of 1998, but that the population level of *P. interpunctella* became very much higher than that of *E. elutella* during the fall. The total number of *P. interpunctella* captured was more than twice the number of *E. elutella* captured (Fig. 1), mostly because of the much larger number of *P. interpunctella* captured during the fall (Fig. 2). The fact that capture rates for *P. interpunctella* were lower than for *E. elutella* during the spring and early summer of 1999 suggests that populations of the latter species may suffer less winter mortality or recover more quickly. This is is consistent with the putative origins of the two species. *E. elutella* is apparently of northern temperate origin and has successfully invaded temperate regions of the Southern Hemisphere. It does not occur in the tropics, however, because it is unable to tolerate prolonged exposure to high temperature (Cox and Bell, 1991), and is one of the few species of *Ephestia* capable of surviving out of doors in the European climate (Richards and Thomson, 1932). *P. interpunctella* is a tropical and warm-temperate species, but it is moderately cold-hardy and can survive most winters in temperate regions.

Table 1. A partial list of the botanicals* stored in a warehouse at Boone, NC, and proximate trap locations for each.

Family	Species	Common name	Parts†	Trap locations‡
Anacardiaceae	*Rhus glabra*	smooth sumac	bark	h
Aristolochiaceae	*Asarum canadense*	wild ginger	root	r
Berberidaceae	*Caulophyllum thalictroides*	blue cohosh	root	h
Campanulaceae	*Lobelia inflata*	lobelia	herb	b
Caprifoliaceae	*Viburnum prunifolium*	black haw	bark	c, d
Compositae	*Echinacea angustifolia*	coneflower	root	j
Compositae	*Liatris odoratissima*	deer's tongue	leaf	o
Ericaceae	*Chimiphila umbellata*	pipsissewa	herb	o
Hamamelidaceae	*Hamamelis virginiana*	witch hazel	bark	f, g, k, n, p
Labiatae	*Scutellaria laterifolia*	skullcap	herb	b
Lauraceae	*Sassafras variifolium*	sassafras	bark, root bark, leaf	s
Leguminosae	*Baptisia tinctoria*	wild indigo	root	k, q
Liliaceae	*Aletris farinosa*	star grass	root	l
Liliaceae	*Trillium pendulum*	beth root	root	n
Loganiaceae	*Gelsemium sempervirens*	gelsemium	bark	l
Myricaceae	*Myrica cerifera*	bayberry	root bark	g
Papaveraceae	*Sanguinaria canadensis*	blood root	root	h, j, k
Phytolaccaceae	*Phytolacca decandra*	poke	root	f
Pinaceae	*Pinus stobus*	white pine	bark	i, q
Polygonaceae	*Rumex crispus*	yellow dock	root	m
Ranunculaceae	*Cimicifuga racemosa*	black cohosh	root	i, k, l
Ranunculaceae	*Hydrastis canadensis*	golden seal	root or herb	m (root), t (herb)
Rosaceae	*Prunus serotina*	wild cherry	bark	c, d, e, q, r, s
Rubiaceae	*Galium aparine*	cleavers herb	herb	m
Rubiaceae	*Mitchella repens*	squaw-vine	herb	p, r
Rutaceae	*Zanthoxylum americanum*	prickly ash	bark	s
Sapindaceae	*Acer rubrum*	red maple	bark	c, d, j
Taxaceae	*Taxus baccata*	yew	bark	r

* Family, scientific and common names according to Torkelson (1996).
† The term herb refers to the entire above-ground part of the plant.
‡ See Fig. 1. Nothing was stored at trap location a.

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